VERIFICATION OF TRANSLATION

Re: International Patent Application WO 03/074207 / PCT/EP03/01775

I, Alex H. Maitland of Hegaustrasse 10, CH-8200 Schaffhausen, Switzerland, am the translator of the document attached and I state that the following is a true translation to the best of my knowledge and belief.

....

Alex H. Maitland

Date: 05.08.2004

Express Mail Label
No. EV342536040US

7/PRTS

10/506446

DT05 Rec'd PCT/PTO 01 SEP 2004

Method for Shaping a Bent Single or Multiple-Chamber Hollow Section by High Internal Pressure

The invention relates to a method for producing bent hollow bodies that copmprise an inner arc and an outer arc forming inner and outer arc wall regions, whereby a starting hollow body is bent and, by means of one or more High-Internal-Pressure (HIP) processes, is transformed in an HIP tool to its final cross-sectional shape, whereby the starting hollow body exhibits a cross-section that is readily bent, at least in its region of bending in which, by means of a specific cross-sectional shape, wall material lies - with respect to bending stress - closer to the neutral stress plane than in the final cross-sectional shape.

Further, the invention also relates to a device for forming bent starting hollow bodies into a final cross-sectional shape or a cross-section close to the final cross-sectional shape using a high internal pressure (HIP) process, whereby the initial hollow body exhibits a cross-section that is readily bent, at least in its region of bending in which, by means of specific profiling, wall material is with respect to bending stress closer to the neutral stress plane than in the final cross-sectional shape, said device containing an HIP tool which accommodates the bent starting hollow body.

In addition, the invention includes the use of the product manufactured using the process according to the invention.

The production of high quality, curved or bent hollow bodies such as e.g. tube-shaped sections, is associated with a large number of difficulties. On the one hand the hollow body should – in particular in the curved region - exhibit as uniform as possible wall thickness, in particular no zones of weakness such as cracks or folds resulting from the forming steps. On the other hand, it should be possible to manufacture the bent hollow body economically and efficiently in as few cold forming steps as possible.

The production of bent hollow bodies normally involves taking a straight starting hollow body which is bent to a given bending radius and bending angle by means of a conventional bending process. The difficulty in bending is to maintain the cross-section in the region of bending. A known method of maintaining the cross-sectional shape in the region of bending is e.g. to introduce mandrels such as

finger-shaped mandrills that are flexible in the direction of bending. This leads, however, to pronounced elongation in the outer lying arc-shaped wall and consequently to excessive thinning of the section wall there, up to the point of forming cracks, while in the inner lying arc-shaped wall region pronounced compression occurs, resulting in a build up of material and folding.

Using that process, therefore, it is possible to realise only limited radii and angles of curvature as a function of the diameter of the hollow section and the thickness of section wall.

With the introduction of high internal pressure processes, hereinafter HIP processes, for forming hollow sections, new possibilities have been opened up in recent years for the production of high quality bent sections. The HIP process is characterised by way of applying high internal pressure via a medium in the interior of the section in a tool cavity into which the hollow section is placed beforehand. This way it is possible to change e.g. the cross-sectional shape of a hollow section.

The modified process for manufacturing bent hollow bodies is characterised by way of conducting a bending process and HIP process in a series of steps. A straight starting hollow section with a cross-section that is readily bent and at that stage does not conform to the final cross-section of the hollow body, is bent using a conventional bending process. The bent starting hollow section is transformed to the final cross-sectional shape in a subsequent HIP process.

The above manufacturing process exhibits the advantage in that the cross-section of the starting hollow section that is to be bent no longer needs to be that of the final bent hollow section. An ideal cross-section permits the mechanical load and the deformation of the section wall in the region of bending to be reduced considerably during the bending process. This progress results in bent hollow sections which exhibit excellent mechanical properties and meet optical requirements also in the bent region.

In spite of the progress attained by the integration of an HIP process, it has been found that when employing the known methods of manufacture, the production of bent hollow sections, in particular tube-shaped hollow sections with very small bending radii and very large bending angles of e.g. 90 – 180° (degrees of angle)

does not meet the high level of requirements with respect to mechanical properties and optical appearance.

Consequently, also with the present day methods of bending and shape-forming there are great limitations with respect to bending radii and bending angles.

The object of the present invention is therefore to provide a process and a device for carrying out the process which permit bent hollow bodies, in particular simple hollow sections, to be produced with small radii of bending and large bending angles.

That objective is achieved by way of the invention in that the HIP tool contains in the inner arc-shaped wall region a slide element, which rests at least in part on the surface of the inner arc-shaped wall region and, during the HIP process, the slide element is withdrawn from the inner arc-shaped wall region in the direction of the the bend opening, with the result that the inner arc-shaped wall region in the starting hollow body is displaced by the high internal pressure in the direction of the withdrawing slide element.

The device is characterised in that the HIP tool contains a slide element at the inner arc-shaped wall region of the bent starting hollow body, and the slide element can be displaced in the direction of the bend opening.

The starting hollow body i.e. the hollow body before the start of the bending and HIP process, is preferably a single or multi-chamber section, in particular a simple hollow section. The starting hollow body or starting hollow section is usefully of metal, preferably steel or aluminium or an aluminium alloy. The starting hollow section is to advantage in the form of a straight hollow section.

The starting hollow section exhibits a cross-section that is readily bent, at least at its length or lengths that are to be bent. The starting hollow section may also exhibit a cross-section that is readily bent over its whole length, whereby the cross-sectional shape and/or size is preferably constant over the whole length of the hollow section.

Is readily bent means that the wall material, by specific shape of the cross-section of the hollow section is as close as possible to the neutral plane with respect to

bending stress – also know as neutral stress plane – so that the smallest possible deformation forces, such as tensile and compressive forces, are applied to the wall material. This way a low polar moment of inertia is achieved. The neutral stress plane then runs through the middle line of the section. Consequently, the wall material of a cross-section that is readily bent is situated close to the middle line of the section.

Cross-sections that are readily bent are, therefore, characterised by flat cross-sectional shapes with relatively height to breadth ratios. Such shapes may e.g. be in the form of upright sections. Also, the cross-sectional shape may be elliptical or oval. Further, the cross-section of the hollow section may exhibit flanking walls bent inwards in the direction of the neutral stress plane e.g. in the form of dents or recesses by means of which a kind of tapering or necking is achieved, whereby the narrowest part of the necking preferably lies at the level of the section middle line. Such a cross-section which is favourable to bending may e.g. be in a form similar to that of an hour-glass, whereby the extent of narrowing at the middle can vary at will.

There are, however, limits to the flattening of the section cross-section, as the said cross-section may not contain too pronounced degrees of curvature in the wall – this because, during the HIP process, the wall material is subjected to very high local deformation at such curvatures, and so can result in places of weakness.

The starting hollow section may be an extruded section which, by means of extrusion, is preferably directly given a cross-section that is readily bent.

The starting hollow section may also be made from a rolled product such as sheet which is shape-formed and joined, in particular by welding. The said starting hollow section may be made with a cross-section that is readily bent, or be transformed into a cross-sectional shape in a subsequent process step. The production of a cross-section that is readily bent may also be an integral process step of the bending process whereby, immediately prior to bending, the starting hollow section is given the readily bent cross-section by appropriate tools.

Suitable bending processes are e.g. draw bending such as rotational draw bending, compression draw bending, press bending, stretch bending or roll bending. The bending process may also be aided by a flexible mandrel insert introduced into the

section interior. Further, alignment and fixing aids such as clamping jaws, bending rolls, sliding rails and/or fold smoothers may assist the bending process.

The bent starting hollow section may feature single or multiple bends, whereby the bending axes may lie parallel to or at an angle to each other. The bent starting hollow section may e.g. exhibit an S-shape with parallel bending axes.

In a preferred version, the bent and HIP-formed hollow section with its final cross-section – in the following designated simply as the final hollow section – features, at least in the inner arc-shaped wall region, a cross-sectional contour which – as viewed from the outside – is curved in a convex manner. In a particularly preferred version the final hollow section is tube-shaped with a circular, elliptical or oval cross-section at least in the bent length. The cross-section at the end of the final hollow section may if desired also contain corners in the outer and/or inner arc-shaped wall region. The uncoiled circumferential length of the easy-to bend cross-section of the initial hollow section may be smaller, larger and preferably of the same magnitude as the uncoiled cross-section of the final hollow section.

In the preferred version of the invention the ratio B of the average bending radius R_m to the tube outer diameter D ($B = R_m/D$) for tubes of metal, in particular aluminium or an aluminium alloy, lies in the range of: $0.5 \leq B \leq 2$, in particular in the range of $0.7 \leq B \leq 1$.

The average bending radius R_m extends from the bending axis to the middle line of the section.

The bending angle may lie in the range of larger than 0° to 180° (degrees of angle). The bending angle preferably lies in the range 40° to 180°, advantageously from 60° to 180°, and in particular from 90° to 180°.

The HIP tool according to the invention contains a basic tool, usefully with two or more parts or tool halves, whereby partially i.e. preferably at least in the region of the outer curved wall, the basic tool forms a cavity to accommodate the bent starting hollow section. The contour of the tool cavity in the region of the outer curved wall may be the contour of the final hollow section, the contour of the bent initial hollow section or a contour lying between these two shapes.

The forming tool contains, in addition to the basic tool, a moveable slide element which forms at least a part of the surface making up the contour of the tool cavity in the inner curved wall region. The slide element has the function here of providing counterpressure. The contour of the slide element forming at least part of the inner arc-shaped wall region of the tool cavity is preferably countershaped to the contour of the bent starting hollow section in the inner arc-shaped wall region.

If the cross-sectional shape of the starting hollow section features a recess in the inner arc-shaped wall region, or if the bent starting hollow section is hour-glass shaped in cross-section, then the slide element preferably has a convex surface form which fits into the depression.

The slide element extends preferably from the inner arc-shaped wall region back to the opening of the bend. Correspondingly, the slide element forms at least part of the contour surface of the tool cavity both in the inner arc-shaped wall region and in the adjacent wall lengths of the neighbouring hollow section flange. The said contour is preferably counter-shaped to the cross-sectional shape of the bent starting hollow section at the said wall parts. As a result, the slide element - on withdrawal in the direction x towards the opening to the bend – is prevented from being blocked by the expansion of the section wall in the wall length of the hollow section flange.

In plan view the slide element fits the curvature of the inner arc and exhibits an arc-shaped end. In a preferred version, the slide element is a tongue shaped in form.

The slide element is preferably such that it is capable of providing resistance to the forces created by the high internal pressures and is thus able to support the inner arc-shaped wall region.

The slide element can usefully be displaced e.g. linearly displaced, and preferably in the direction of the bend opening x. Further, the slide element is preferably connected to an alignment facility guiding the slide element. The alignment facility may if desired contain a drive unit.

The slide element is to advantage introduced between the an upper and a lower tool half.

On carrying out the process according to the invention the starting hollow section, which is bent and, at least in the length to be bent has a cross-section that is readily bent, is laid in the cavity of a basic tool.

Subsequently, a high internal pressure is applied, whereby, in the outer arc-shaped wall region, the starting hollow section is pressed into the contour of the tool cavity. During the HIP process, the slide element is withdrawn, in the direction x of the bend opening, a specific distance out of the inner arc-shaped wall region, whereby the inner arc-shaped wall region in contact with the slide element is pushed by the high internal pressure. The high internal pressures can e.g. amount to 500 – 2000 bar.

When the slide element has reached its predetermined final position, the HIP process is completed and the part removed from the tool. In the inner arc-shape wall region the resultant hollow section exhibits a cross-sectional shape which corresponds to or is close to that of the final hollow section.

Subsequently, the hollow section is placed in a further forming tool, the cross-section of which corresponds to that of the final hollow section.

By optimal design of slide element it is also possible to achieve the final cross-section of the hollow section in the first HIP forming step.

The process according to the invention permits the production of bent tubes with large bending angles and extremely small bending radii in a multi-stage cold forming process. The use of a slide element according to the invention makes it possible to control the flow of material caused by the cross-sectional shaping process in the inner arc-shaped wall region. In the cross-sectional shaping by conventional processes all flow of material was in the direction of expansion of the section cross-section i.e. in the radial direction. This, however, leads to thickening of the wall and to folds. By employing a slide element which specifically controls the radial flow of material, lateral flow of material is achieved along the surface of the slide element in the direction of the wall region of the section flange neighbour-ing the internal arc-shaped wall region. The thickening of the wall in the internal arc region is thus reduced and the formation of folds prevented.

The process according to the invention permits hollow sections, in particular tube-shaped hollow sections with very small bending radii and large bending angles to be manufactured, viz., such as are not achievable using conventional processes. Further, the process according to the invention allows the use of hollow sections with comparably small wall thickness, achieving as a result a savings in material.

Using the process according to the invention it is possible to manufacture e.g. singly or multiply bent input manifolds e.g. suction pipes for internal combustion engines, preferably for internal combustion engines for vehicles. The internal combustion engines on which the mentioned manifolds find application are preferably internal combustion engines functioning according to the Otto principle or that of the diesel engine, in particular suction engines, turbo supercharged or compressor charged engines.

Singly or multiply bent tubes manufactured using the process according to the invention can also be employed as automobile body parts e.g. space-frame components, engine suspension, chassis components, components for exhaust gas units e.g. bent tubes, and as constructional or component parts e.g. for wing spars, bow-wing skids, or roll bars. Further, singly or multiply bent tubes manufactured using the process according to the invention can find application in pipelines of all kinds e.g. for conveyance of liquids and gases under pressure such as hydraulic pipelines, as railings and for further applications in the construction of vehicles, ships and aircraft as well as in above or below ground level building.

The invention is described in the following in greater detail by way of examples and with reference to the accompanying schematic drawings. These show in:

Fig. 1: a perspective view of a bending process;
Fig. 2 a perspective view of a bent starting hollow section;
Fig. 3: a perspective view of a first HIP process according to the invention;
Fig. 4a-c: a perspective view of a second HIP process for manufacturing the final hollow section;
Fig. 5a-f: a cross-section through the position A-A in Fig. 3 in various stages of the first HIP process;
Fig. 6a-b: a cross-section through the position B-B in Fig7 in various stages of the second HIP process;
Fig. 7: a plan view of a final hollow section;

Express Mail Label
No. EV342536040US

Fig. 8: a graphic representation relating to the feasibility of 90° bending of tube-shaped sections.

Figs. 1 – 7 show illustrations obtained from process simulations, whereby the grid contour lines correspond to the middle planes of the body being bent or the surfaces of the forming tool. The figures show therefore only schematically simplified illustrations for the purpose of explaining the process and device according to the invention.

The following example illustrated in Figs. 1 – 7 relates to the manufacture of final hollow sections of circular cross-section and a bending angle of 180°. The hollow sections shown are only extracts from hollow sections of any desired length featuring e.g. straight or further bent lengths.

Fig. 1 shows how, using a conventional bending process, a bent starting hollow section 10a (Fig. 2) is produced from an originally straight starting hollow section 5 e.g. an extruded section with a readily bent cross-section, whereby the bending device 1 employed for that purpose contains a guide rail 2 for the starting hollow section 5 and a bending roll 4 for bending the starting hollow section 5. The starting hollow section 5 is held by a clamping jaw fixed to the bending roll 4 which subsequently bends the fixed starting hollow section 5 by means of a rotational movement. During the bending operation the starting hollow section 5 is fed in the guide rail 2 in the direction of the bending roll 4.

The starting hollow section 5 has a readily bent cross-section which is produced e.g. by means of a forming process or directly by extrusion. The production of the starting hollow section 5 with readily bent cross-section and the bending process are independent of subsequent process steps in which the bent starting section 10a is shape-formed into the cross-section of the final hollow section 10g; i.e. other bending processes may be used.

The bent starting hollow section 10a has an especially preferred readily bent cross-sectional shape which is characterised by way of two mirror image recesses 13a,b, whereby the recesses 13a,b form a kind of necking in the middle. The mirror image arrangement relates to an axis 14 or plane running parallel to the bending axis. The bent starting hollow section 10a features an outer arc with outer arc wall region 11 and an inner arc with an inner arc wall region 12, whereby the inner and outer arc

wall regions are usefully delimited with respect to each other by the neutral stress line or plane 14, 65 running parallel to the bending axis.

Fig. 3 shows the arrangement of a part of the HIP tool after conclusion of the first HIP process. The hollow section 10e lies in a lower half 22b of the tool. For reasons of clarity, the upper half of the tool is not shown here. Inserted into the inner arc wall region of the hollow section 10e is a slide element 21 which in the course of the process has been withdrawn a specific distance in the direction x towards the bend opening and has now reached its end position, so that the inner arc wall region in contact with the slide element 21 is able to expand in the direction x of the withdrawing slide element 21 and take on a contour which is approaching that of the final hollow section. Viewed in plan view, the slide element 21 exhibits a tongue-shaped form corresponding to the curvature of the inner arc wall region.

To carry out the second HIP process, the hollow section 10e is placed in a second HIP tool (Fig. 4a-c), which defines the final contour of both the inner and outer arc wall region. The outer arc wall region of hollow section 10e has already been shaped to the contour of the final hollow section which is given by the tool cavity. Further, the inner arc wall region has already been expanded in the region of most pronounced curvature, approximately to the cross-sectional shape of the final hollow section (Fig. 4a). The hollow section 10e is now transformed by the action of the high internal pressure into the cross-sectional shape of the final hollow section 10g (Fig. 4b-c). For reasons of clarity only the lower half 32b of the HIP tool is shown schematically here.

Figs. 5a-f show in a series of steps the first HIP process according to the invention as seen along the line A – A in Fig. 3. A bent hollow section 10a (see also Fig. 2) with a readily bent cross-section according to Fig. 2 is placed in a forming tool 22 in the form of a cavity and having an upper half 22a and a lower half 22b and the tool closed. A slide element 21 which forms the cavity wall over at least one wall area of the inner arc wall is moved before, after or along with the closing of the two tool halves 22a,b, up to the inner arc wall region of the bent starting hollow section 10a. The contour of the slide element 21 in contact with the inner arc wall region of the starting hollow section 10a is identical to the contour of the concave inner arc wall region. In the present example the said contour of the slide element 21 corresponds to that of a torus.

After preparation for forming, a high internal pressure is applied to the section interior 43, whereby in a first step the outer arc wall region of the hollow section 10b is pressed into the contour of the tool cavity, whereby the tool cavity exhibits in the outer arc wall region the contour of the final hollow section.

The slide element 21 is subsequently drawn back in direction x towards the bend opening, whereby the inner arc wall region follows it under the action of the high internal pressure and increasingly approaches or takes on the contour of the final hollow section (Figs. 5b-f).

When the slide element 21 reaches its end position, the high internal pressure is reduced, the hollow section 10e the contour of which is now closer to that of the final hollow section in the inner arc wall region is removed (see also Figs. 3, 4a) and introduced into a second HIP tool 32 with upper and lower tool halves 32a, 32b. The second HIP tool 32 has the contour of the final hollow section 10g, i.e. both in the inner arc wall region and in the outer arc wall region. The hollow section 10e, 10f is then shaped into the contour of the final hollow section 10g in a second HIP process step.

Of course it is possible to carry out the shape-forming of the outer arc wall region 11, 61 to the cross-sectional shape of the final hollow section 10g in a second HIP process step. That is, the HIP tool 22 operating with the slide element 21 features in the outer arc wall region 11 the contour of the bent starting hollow section 10a or a contour which lies between that of the starting hollow section 10a and the final hollow section 10g.

Fig. 7 shows in plan view the final hollow section 10g (see also Fig. 4c) which has been bent to a circular cross-sectional shape. The bending plane or line 65 also forms the middle line of the section and is also the reference plane for the bending radius R_m. The grid lines 63 illustrate the flow of material within the section walls, whereby grid lines that are pressed close together indicate an accumulation of wall material and widely spaced grid lines indicate a reduction in the wall material. As can be readily seen from Fig. 7the final hollow section 10g exhibits remarkable flow of material 66 (arrows) from the inner arc wall region 62 in direction x towards the bend opening, i.e. in the direction of both adjacent section flanges 67a, 67b. The said flow of material is effected by the above mentioned slide element 21, in that the wall material is forced under the action of the high internal pressure and the

resistance of the slide element 21 to flow along the adjacent face of the slide element 21 from the inner arc wall region 62 outwards in the direction of the walls of the section flanges 67a, 67b. By drawing back the slide element 21 the wall material of the inner arc wall region 62 is led outwards in a controlled manner radially, while approaching the cross-sectional shape of the final hollow section 10g, whereby as a result of the simultaneous flow of material towards the section flanges 67a, 67b folding in the inner arc wall region is prevented. Further, using the process according to the invention it is possible to reduce the reduction in wall thickness.

Fig. 8 shows a graph 50 relating to applications for 90° bending of tube-shaped sections of a typical aluminium alloy, here as a function of tube diameter, bending radius and wall thickness.

Plotted on the horizontal axis is the ratio of average bending radius Rm to the outer diameter D of the tube and on the vertical axis the ratio of tube outer diameter D to wall thickness t. The shaded area 51 shows the ranges within which 90° bending is possible, whereby the feasibility refers to a conventional bending process. The region outside the shaded area delineated by a straight line represents that range in which successful bending is no longer guaranteed.

If e.g. a tube which has to be bent has a diameter D of 20 and a wall thickness of 1, then Fig. 8 shows that the said tube can be bent to 90° with a bending radius of 40 as the ratio $R_m/D = 2$ and the ratio $D/t = 20$, and the intersection lies in the shaded area. If, however, a bending radius Rm of 30 is chosen for a tube of the same dimensions, the intersection lies in the range in which bending cannot be successfully carried out, i.e. it can be assumed that the tube will fail.

Using computer simulations it was possible to show that using the process according to the invention it seems possible to produce bent tubes of an aluminium alloy, which have bends lying in the non-feasible range in Fig. 8. Further, using computer simulations it seems possible using the said process to achieve bends with a bending radius that is equal to or smaller than the diameter of the tube. It was therefore possible in a computer simulation successfully to bend a 56 mm diameter tube of 2.5 mm wall thickness to a bending radius of 40 mm using the process according to the invention. Point 52 in Fig. 8 shows the relevant ratios,

whereby it is evident that tubes with the said dimensions and bending radius could not be bent satisfactorily using conventional bending processes.